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DETERMINATION OF ELECTRON DENSITY IN THE IONOSPHERE BY ANALYSIS OF POLARIZATION FADINGS OF SATELLITE OR ROCKET SIGNALS *

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by S. A. Namazov

ABSTRACT

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Examined is in this paper the phenomenon of radiowave polarization plane rotation in case of waves emitted by a transmitter of a rocket or an artificial satellite. The discussion centers on the possible method of obtaining the distributions of electron concentration in the observed altitude range by the recordings of polarization fadings of signals emitted by rocket or satellite transmitter. A possible principle is proposed for the construction of a device measuring the frequencies of polarization fadings.

INTRODUCTION

For the study of the ionosphere above the F-region maximum (upper ionosphere), which is not accessible to radiosounding from the ground, the phenomenon of rotation of radiowave polarization plane (Faraday effect), observed during radar location of the Moon [1 — 3] has been successfully applied during the latest years. in the case of signal reception that are emitted by transmitters from satellites and high flying rockets.

* Opredeleniye kontsentratsii elektronov v ionosfere na osnove analiza polyarizatsionnykh zamiraniy signalov iskusstvennogo sputnika Zemli ili rakety.

The simplicity of the setup of such an experiment and the reliability of the results obtained on the state of the ionosphere open broad possibilities for such study. The current paper describes the method.

1. ROTATION OF THE POLARIZATION PLANE.

As is well known, in the presence of the Earth's magnetic field, the ionosphere is a medium with double refraction : the radiowave propagating through it is split into two components (waves) — the ordinary and extraordinary. These components propagate with different phase velocities. That is why in leaving the ionosphere they have a phase shift, which leads to the rotation of the polarization plane of the total wave (Faraday effect).

If the emitter moves (as is the case for rockets and satellites), a continual rotation of the polarization plane is observed. The signal, received by a lineraly-polarized antenna, undergoes polarization fadings, whose frequency is determined by the rotation speed of the polarization plane of the incident wave.

The mathematical expression describing the rotation of radiowaves' polarization plane after their passing through the ionosphere, is obtained from the phase difference between the two waves of the magneto-ionic splitting.

The rotation angle of wave's polarization plane along the propagation path in the ionosphere, may be represented in the form (See Appendix) :

$$\Omega = \frac{k}{f^2}\overline{M}\int_{h_1}^{h_2(l)} N(h)\,dh. \qquad (1)$$

under the following simplifying admissions : a) fulfilment of the condition of the quasilongitudinal approximation, b) the wave's frequency considerably exceeds that of plasma and giromagnetic frequencies, c) refraction and propagation trajectory coincidence are absent in the ionosphere for wave's components, d) uniformly-

laminar (stratified) structure of the ionosphere.

Because of the indeterminentness appearing at determination of its value ($n\pi$), the direct measurement of the total angle of rotation of the polarization plane (Ω) is not possible. Only the rotation speed of the received wave's polarization plane may be experimentally measured:

$$\frac{d\Omega}{dt} = A\left[N_s\overline{M}\frac{dh_s}{dt} + \frac{\partial\overline{M}}{\partial t}\int_{h_s}^{h_s(t)} N(h)\,dh\right]. \qquad (2)$$

In the general case, expression (2) does not allow to determine separately the integral content and concentration of electrons by the measured value in one frequency of the rotation speed of the polarization plane.

However, at present a series of methods are known, which overcome the above-noted difficulties and permit the determination of ionosphere parameters by the expressions (1) and (2). These methods allow to determine by polarization fading of signals from rockets and satellites the integral electron content to the height of their position [4 - 8], and also the degree of ionization drop above the region's maximum [9]. Using signal polarization fadings one may determine both, the integral electron content [11] and the electron concentration [10], which is found by averaging the integral content for the fading period.

2. DISTRIBUTION OF ELECTRON CONCENTRATION IN THE OBSERVED ALTITUDE RANGE.

Described below is a method, allowing to determine the distribution of electron concentration N_s (h) in the observed altitude range relative to a certain value N_a, known at any given point of emitter position in the course of observation time.

Taking into account that $\Omega = \pi \int_{t_0}^{t} F(\tau)\, d\tau$, it is easy to obtain from the correlations (1) and (2) an expression for the electron concentration N_s at the point of emitter's position in the form

$$N_s = \frac{\pi}{A\overline{M}h_s'}\left[F(t) - \frac{\overline{M}'}{\overline{M}}\int_{t_0}^{t} F(\tau)\, d\tau\right], \qquad (3)$$

where $\overline{M}' = \partial\overline{M}/\partial t$; $h_s' = dh_s/dt$; $F(t) = \frac{1}{\pi}\frac{d\Omega}{dt}$; t_0 is the beginning of count (corresponding to the moment $\Omega = 0$); t is the current time.

Expressing N_s through the value of electron concentration in an arbitrary point **a**, we obtain

$$N_s = \frac{h_a'\frac{\overline{M}'}{\overline{M}^2}}{h_s'\left(\frac{\overline{M}'}{\overline{M}^2}\right)_a} N_a + \frac{\pi}{A\overline{M}h_s'}\left[F(t) - \frac{\frac{\overline{M}'}{\overline{M}}}{\left(\frac{\overline{M}'}{\overline{M}}\right)_a} F(t_a) - \frac{\overline{M}'}{\overline{M}}\int_{t_a}^{t} F(\tau)\, d\tau\right], \qquad (4)$$

where N_a is the electron concentration at the point **a**; $F(t)$, h'_s, $\overline{M}$ and $\overline{M}'$ are respectively the frequency of polarization fadings the vertical component of emitter's velocity, the values $\overline{M}$ and $\overline{M}'$ at the considered moment of time. $F(t_a)$, h'_a, $\overline{M}_a$ and $\overline{M}'_a$ are the respective values of the indicated quantities at the moment of time when the emitter is at the point **a**.

The expression (4) is represented in the form of two components. The first contains the value of electron concentration at an arbitrarily selected point **a** of the considered altitude interval and certain factor, which is expressed through the well known coordinates of the position and the motion velocity of the emitter and the parameters of the Earth's magnetic field. Let us note, that inasmuch as that factor near N_a contains quantities upon which the rotation angle of the polarization plane depends, it will not remain constant in the course of observation time. Experimentally determined quantities with corresponding factors are included in the second component (in brackets).

Let us consider certain possible cases of obtention of electron concentration distribution.

1) If the observed altitude interval within the limits of which there are registrations of a signal with polarization fadings, starts from the lower boundary of the ionosphere h_o (as for example in rocket investigations), we obtain , by choosing $N_a = N_o = 0$, the curve for the variation of electron concentration N_s, beginning with h_o.

2) If the observed altitude interval encompasses the maximum ionization region, by selecting $N_a = N_{max}$, we shall obtain the variation of electron concentration relative to N_{max}.

3) But if the very same altitude interval is significantly above the F-region maximum, we may apply the method of ref. [9]* for the determination of N_a , corresponding to the altitude h_a, and then compute the curve of N_s variation relative to N_a. To determine N_a by the indicated method, it would apparently be more correct to utilize the exponential drop of ionization above the maximum, and not the linear, as this is done by the authors of reference [9].

The last two cases are related mainly to the investigation of the ionosphere with the help of artificial satellites. Therefore, being in possession of satellite transmitters' signal readings with polarization fadings for a prolonged time, one may obtain the distribution of electron concentration correspondingly along the satellite orbit (or rocket trajectory), and consequently also the distribution of electron concentration in the observed altitude range.

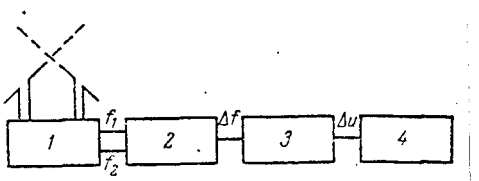
It is necessary to note that the expression (4) is obtained for the above-indicated simplifying admissions. At the same time, the correction for the "high-frequency" approximation should be made analogously [5]. As for the remaining admissions, it should be made similarly to [5, 15, 16], or on the basis of an exprimentally obtained curve for the distribution of ionization.

*) See comments in appendix.

3. DEVICE FOR THE MEASUREMENTS OF THE FREQUENCY OF POLARIZATION FADINGS.

The singling out of polarization fadings from the received signal is often complicated by signal fluctuation, conditioned by other causes (emitter's rotation, radioblinking etc..). That is why it is useful to realize a device permitting the separation of polarization fadings from the fluctuating signal and the obtaining at the output a direct curve for the variation in time of the frequency of polarized (Faraday) fadings.

The proposed possible principle of construction of such a a device is based upon the subdivision of the received wave into an ordinary and extraordinary components, and on the separation of these oscillations' difference frequency, inasmuch as the frequency of polarization fadings is equal to the semi-difference of Doppler shift frequencies for these components. The block-diagram of the device is shown in the figure hereafter.



The signal must be received on two orthogonal dipoles, and they must be so disposed, that the phase shift constitute 90°. Further the signal has to be fed to the divided scheme — the ordinary and extraordinary components (block 1). The isolation of the difference frequency $\Delta f = f_2 - f_1$ takes place in block 2. This difference frequency is fed to the frequency discriminator (block 3), at whose output obtained is a voltage Δu, proportional to Δf. Then this voltage is fed to the registering device (block 4). The curve obtained in this way will show the variation in time of the frequency of polarization fadings.

CONCLUSION

On the basis of the above-expounded, we may draw the following conclusions :

a) Valuable data on the state of the ionosphere above the F-region maximum may be obtained according to polarzation fadings of signals from rockets and satellites ;

b) The proposed methods allows the determination of the distribution of electron concentration in the considered altitude range by rocket and satellite signals' polarization fadings ;

c) The realization of the appropriate device to measure the frequency of polarization fadings applying the proposed principle will allow to fully separate the fadings of polarizational character from other types of fading.

* * *

A P P E N D I X

1. REFRACTIVE INDEX

It is easy to show that at relatively high frequencies, when they are significantly higher than the plasma or the giromagnetic frequencies and of collision frequency, the condition for the quasilongitudinal approximation (QL) is, as a rule, fulfilled for all angles $\theta < 80^\circ$ [9].

The refractive index for the QL-approximation, expanded in exponential series for $\omega \gg \omega_H$ and $\omega \geqslant \omega_0$, will take the form

$$n = \left[1 - \frac{U}{1 \pm u_L}\right]^{1/2} = 1 - \frac{1}{2} U (1 \mp u_L) - \frac{1}{8} U^2 (1 \mp u_L)^2 - \\ - \frac{1}{16} U^3 (1 \mp u_L)^3 - \frac{5}{128} U^4 (1 \mp u_L)^4 - \ldots, \qquad (5)$$

where ——— $U = \omega_0^2 / \omega^2$; $u_L = u \cos\theta = \omega_L / \omega$; $u = \omega_H / \omega$; $\omega_H = He/mc$ is the giromagnetic frequency — $\omega_0^2 = 4\pi Ne^2/m$ is the plasma frequency; θ is the

angle between the direction of propagation and the vector of the Earth's magnetic field.

2. ROTATION ANGLE AND REVOLUTION SPEED OF THE POLARIZATION PLANE.

The phase difference between the component of magnetoionic splitting or the rotation angle of the polarization plane (Ω) is written as

$$\Omega = \frac{\omega}{c}\left\{\int_{(l_1)} n_1 dr - \int_{(l_2)} n_2 dr\right\}, \qquad (6)$$

where n_1 and n_2 are the refraction indices of the ordinary and extraordinary waves; l_1 and l_2 are their respective propagation paths.

If we do not take into account the difference in propagation trajectories of wave's components, the refraction of the beam in the ionosphere, and if we limit ourselves by the first term of the expansion (5), which is acceptable for , and if moreover we pass from the element path to the element height, we obtain

$$\Omega = \frac{k}{f^2}\int_{h_0}^{h_s(t)} NM\,dh = \frac{k}{f^2}\,\overline{M}\int_{h_0}^{h_s(t)} N(h)\,dh, \qquad (7),$$

where $k = e^3 / 2\pi m^2 c^2 = 2.36 \cdot 10^4$ (Gauss unit system); f is the wave's frequency in mc/s ; N is the electron concentration expressed in electrons per cm^3; $M = H\cos\theta\sec\delta$; H is the intensity of the Earth's magnetic field in gauss ; h_o is height of the lower boundary of the ionosphere ; δ is the zenithal angle ; Ω is the rotation angle in rad.

At heights below 1000 km, the quantity $M = \cos\theta\sec\delta$ varies insignificantly along the wave propagation path, and that is why its averaged value may be taken out of the integral [1]. According to [14] the averaged value $\overline{M}$ corresponds to the true value M at altitudes from 340 to 400 km for an average ionosphere profile.

The expression (7) was obtained following a series of simplifying admissions. Thus correction must be introduced in the final result for the high-frequency approximation, the refraction, the difference in propagation trajectories of wave components and the presence of horizontal gradients in the ionosphere

The integration of (7) is effected along the propagation path of the wave in the ionosphere, while the upper limit of the integral corresponds to the position of the emitter at the considered moment of time, i.e. $h_s = h_s(t)$. It is not difficult to show that in this case the time will enter into the sub-integral expression as a parameter, and the upper limit of the integral will also be the parameter's function.

In such form the expression (7) was first obtained in [1] and it was applied for the determination of the integral content of electrons in the ionosphere by the rotation of the polarization plane of waves reflected from the Moon [2, 3].

The link of the ionosphere parameters with polarization fadings, which is observed experimentally at signal reception from satellites and rockets, is found by differentiation of (7) in time (or by the parameter). The differentiation of the expression (7) in the assumption of "congealed" ionosphere and invariability of electron distribution at its lower boundary in time of observation leads to the correlation [13]

$$\frac{1}{A}\frac{d\Omega}{dt} = N_s\overline{M}\ \frac{dh_s}{dt} + \frac{\partial\overline{M}}{\partial t}\int_{h_0}^{h_s(t)} N(h)\,dh + \overline{M}\int_{h_0}^{h_s(t)} \frac{\partial N}{\partial t}\,dh, \qquad (8)$$

where the index s indicates, that these quantities are related to the point of emitter's location, while the line over M designates the averaging of this quantity along the propagation trajectory.

Because of its smallness, the last component is usually neglected [8]. The final expression for the speed of polarization plane rotation has the form [12]

$$\frac{1}{A}\frac{d\Omega}{dt} = N_s \overline{M}\frac{dh_s}{dt} + \frac{\partial \overline{M}}{\partial t}\int_{h_0}^{h_s(t)} N(h)\,dh. \qquad (9)$$

Therefore, the rotation speed of the polarization plane of the received wave depends upon both, the integral electron content along the propagation trajectory, and the electron concentration at the point of emitter's location.

For artificial satellites, the integral electron content may be determined from the expression (9) only for certain particular positions of the satellite : in perigee or apogee ($dh_s / dh_t = 0$), in circular orbit ($dh / dt = 0$), at great altitudes ($N_s = 0$). In the general case the problem of separated determination of the integral content and electron concentration by the known rotation speed of the polarization plane in one frequency cannot be the object of a strict solution.

*** THE END ***

Entered on 1 Aug.1961.

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* Infrapaginal note from page 5.

In the work ref. [9], a correlation, allowing to determine the ionization drop above the F-region maximum, was obtained by way of analysis of the expression describing the rotation angle of the polarization plane for two positions of the satellite in orbit, separated by a time interval of 30 seconds, provided the number of fadings in the considered time interval is known through experimental data, and on condition that the ionosphere model is chosen accordingly, using the data of ionospheric stations.

Translated by ANDRE L. BRICHANT
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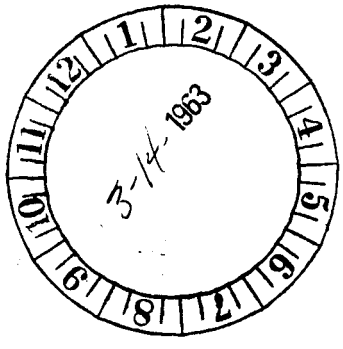
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